EXPERIMENTAL INVESTIGATION OF DRILLPIPE LOADED IN SLIPS

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ABSTRACT
Oilwell drillstrings are suspended in the rotary table using axisymmetric wedges in a restraining bowl structure. These wedges, known as “slips”. Hardened dies on the inside surface of the slips grip the drillpipe. The string capacity to sustain axial loads is influenced by the slip-drillpipe interaction.

When the design for a recent Gulf of Mexico (GOM) offshore well required the drillstring to support ~4.5 kN, a test program to investigate slip-drillpipe interaction was initiated. The analysis of strain gage data revealed that drillpipe peak stresses are not confined to a single cross sectional plane on the drillpipe ID. Yielding is initiated on the ID along a line parallel to the drillpipe axis, and corresponds to the gap between slip segments. This paper presents test details and results of data analyses that are a prelude to an ongoing effort to determine a revised design basis for drillpipe loaded in slips.

INTRODUCTION
The discovery and development of offshore reservoirs in waters deeper than 1800 m. requires drillstrings whose weight approaches or exceeds 5 kN. This creates a design and operational challenge, principally via the slips and their interaction with the drillpipe. By treating the slip as an axisymmetric wedge, the axial load required yield the drillpipe ID can be calculated. This load, known as the Reinhold-Spiri slip crushing load (SCL_y) was proposed in 1959 [1] and verified by limited testing conducted on 127 mm (5 in.), 23.9 kg/m, (19.5 lbm/ft), Grade E (min. yield strength 517 MPa (75,000 psi)) drillpipe in 1962 [2].

Though the SCL_y has been used to design drillstrings, investigations of recent field failures indicate that the SCL_y may be non-conservative with respect to the yield load of the drillpipe, and that drillpipe behavior in slips is a complex function of slip geometry, friction between the slip and the bowl and mechanics of load transfer between the slip and drillpipe [3].

One of the deepwater GOM wells in BP America’s portfolio requires a custom built 168.3 mm (6 5/8 in.), 37.1 kg/m (30.3 lbm/ft) (wall thickness 11.7 mm (0.460 in.)), Grade V-150 (min. yield strength 1,034 MPa (150,000 psi)) steel drillpipe. The basis of design for this drillstring assumes an SCL_y of 3.4 kN (771 kips). Depending on the coefficient of friction (μ) between the slip and the bowl, the SCL_y has a value between 4 kN (910 kips) (μ = 0.08) and 4.6 kN (1,035 kips) (μ=0.2). In Fall 2003, the drilling team decided to measure the slip crushing capacity of the drillpipe by loading it in the slip assembly shown in Fig. 1.

TEST PROGRAM
Forty rosette strain gages were installed (at equal intervals) on the pipe ID in eight cross sectional planes (see Fig. 2). The test procedure included a series of loading-unloading cycles whose purpose was to investigate the effect of slip geometry on drillpipe stresses. With each cycle, the relative orientation of the slip with respect to the pipe was incremented circumferentially by 6°. To ensure that stresses in the drillpipe were elastic, the peak axial load was maintained below 1.8 kN (400 kips) in these initial cycles. After 24 such load cycles, the test specimen was pulled to a final axial load of 5 kN (1,137 kips). In the final load cycle, whose purpose was to determine the slip crushing capacity of the drillpipe, one of the five strain gage columns was coincident with one of the gaps between slip segments.

RESULTS AND DISCUSSION
The axial strain profiles on the drillpipe ID in Fig. 3 imply that the drillpipe axial stress is approximately constant at a given cross section, but decreases away from the slip toe.
This is consistent with the fact that string weight is distributed across the pipe cross section and is gradually transferred to the slips. However, the hoop strains reflect asymmetries of radial loading on the drillpipe. Importantly, the locus of peak hoop stress is a line parallel to the axis of the drillpipe, and is coincident with the gap between the slip insert carriers. Since this section of pipe behaves as a curved beam subjected to bending, yielding initiates along this line and migrates radially and circumferentially with increasing axial load.

Figure 4 shows the equivalent strain profiles at the pipe ID at the 72° location as a function of axial load. Superimposed on these strain profiles is the true-stress versus true strain curve obtained from a uniaxial tension test on a drillpipe sample. The figure shows that yielding is initiated in the drillpipe at an axial load between 2.2 kN (500 kips) and 2.7 kN (600 kips). Importantly, the figure suggests that failure is likely to occur as a result of a “hinge” mechanism in the pipe section between slip segments rather than by radial crushing in the plane of the slip toe. Anecdotal evidence regarding a recent drillpipe field failure tends to support this hypothesis. Also, tests performed with other drillpipe sizes and slip geometries show similar strain patterns.

SUMMARY REMARKS

As shown in Fig. 4, the drillpipe retains significant structural integrity even when it is subjected to loads more than twice the value required to initiate yielding. Though yielding in the pipe is initiated at loads substantially less than SCLy, the degree of yielding at expected operational loads must be established. Such an analysis establishes the stress distribution in the drillpipe cross section, which in turn may be used to estimate the load carrying capacity of the bi-axially loaded drillpipe. If yielding at operational loads is localized (as tests appear to indicate), the drillpipe can potentially have sufficient axial load carrying capacity, even when the predicted SCLy is exceeded. However, this assessment can only be made with finite element analyses (FEA) and/or analytical work that uses the results of testing to calibrate a theoretical model. In this light, the notion of SCLy, which relies on the recognition of incipient yield in the pipe, must perhaps be replaced by a notion of drillpipe integrity.

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